

Data Analysis and Modeling to Support NOWCAST and Forecast Activities at the Fallon Naval Air Station

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LONG-TERM GOALS

The goals of this project are to increase our understanding of weather predictability and to develop capabilities to provide more accurate forecasts and nowcasts in complex terrain using ensemble modeling techniques and special observations including remote sensing.

OBJECTIVES

The main objectives of the study are: 1) To develop and test a mesoscale forecasting system with sub-kilometer horizontal resolution to support the NOWCAST system at the Fallon Naval Air Station (NAS); 2) To improve the accuracy of the forecasts and nowcasts by assimilating asynchronous data into the forecasting system; 3) To provide short-term accurate predictions of cloud structure, especially for the clouds such as the stratus cloud decks and fog, that are relevant to visibility for the Navy's aircraft operations in the complex terrain; and 4) To develop methods of mesoscale ensemble forecasting to improve the applicability of the forecasts and nowcasts.

APPROACH

We have developed a fully self-sustained MM5 real time forecasting system to support NAS Fallon operations. The system has been tested and it is now in operation on a multi-processor computer located in the Division of Atmospheric Sciences at the Desert Research Institute (DRI).

Briefly, the main characteristics of the real time forecasting system are:

- The system results are posted on the dedicated web site with password protection [URL: <http://www.adim.dri.edu/>] and are updated with model runs every 12 hrs.

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- 24-hr forecasts are provided for five interactive domains with the highest sub-kilometer resolution (330m) on the innermost domain centered on the NAS Fallon runway.
- A new automatic pre-forecast data assimilation simultaneously using
 - Data from four meteorological stations that were set up in the NAS Fallon area during a previous ONR project.
 - WSR 84 Fallon radar data.
 - Satellite data (a new methodology of improving model initial conditions in the vicinity of the NAS Fallon area, and the initial boundary layer height over the entire model domain).

A new component of our study was the determination of the optimum utilization of satellite data for monitoring and predicting the short-term physical characteristics of boundary layer cloud and thermodynamic conditions in the vicinity of the cloud top. A method has been developed to estimate cloud-top height for low-level clouds by combining the above-cloud information extracted from the satellite imagery and the below-cloud information obtained from weather station measurements (Vellore et al. 2006). A schematic of the satellite data assimilation system is shown in Fig. 1. A real-time algorithm was developed to create improved air temperature and dew point profiles for the entire troposphere which are representative of the Fallon area. The representative area is a circular region of 60 nautical miles (approximately 110 km) that encloses Reno and is centered at Fallon (39°19'27" N, 118°13'22" W, 4235' MSL). Reno (39°29'02" N, 119°46'16" W, 4412' MSL) and Elko (40°52'00" N, 115°44'00" W, 5270' MSL) soundings were used to construct the representative/synthetic sounding at the Fallon location. Cloud types (low, middle, and high clouds) derived from the satellite derived cloud-top temperature (CTT) were identified with reference to the temperature values of the synthetic sounding at 700 and 400 hPa, i.e., cloudy pixels that contain low clouds or fog are identified if the satellite derived CTT is greater than the temperature value at 700 hPa; if the CTT obtained from the pixels lies between 400 and 700 hPa, the pixels contain middle level clouds; and if the CTT is less than the temperature at 400 hPa, the pixels contain high clouds. Further classification of cloud types based on the satellite channel derived brightness temperature limits used the work of Lee et al. (1997). Cloud free pixels were identified with reference to the CTT and the average surface air temperatures of Reno and the Fallon B17 station. If the circular region is cloudy, the representative sounding at the Fallon location is modified using an iterative procedure by forcing the sounding into saturation between the cloud base (information obtained from the ceilometer observations and/or condensation levels obtained from adiabatic calculations) and cloud top.

We have tested the efficiency of the real-time forecasting system on a multi-processor computer and this has provided guidance on which aspects of the model structure the execution time is most sensitive.

Ensemble forecasts provide human forecasters with a range of possible solutions whose average is generally more accurate than a single deterministic forecast. It also provides a quantitative basis for probabilistic forecasting (Lewis 2005; Lewis et al. 2006) for the operational weather forecasting sectors. Our approach is to conduct an investigation on the potential effectiveness of ensemble forecasting for the Fallon real-time forecasting system using a 'Lagged Average Forecasting (LAF) method' following Hoffman and Kalnay (1983) by creating ensemble members of different ages (i.e., at different initial times, not by different set of initial perturbations at a specific time as in the Monte Carlo approach). For evaluation, we selected a case study of high winds and a dust storm event during February-March 2002 in western Nevada. Reno and Fallon surface observations indicated a sudden gusty spell of wind, rising to more than 10 m s^{-1} on 28 February 2002. These conditions are faced by

the Fallon NAS staff and pilots – creating significant issues related to wind forecasting and visibility as they affect aircraft operations.

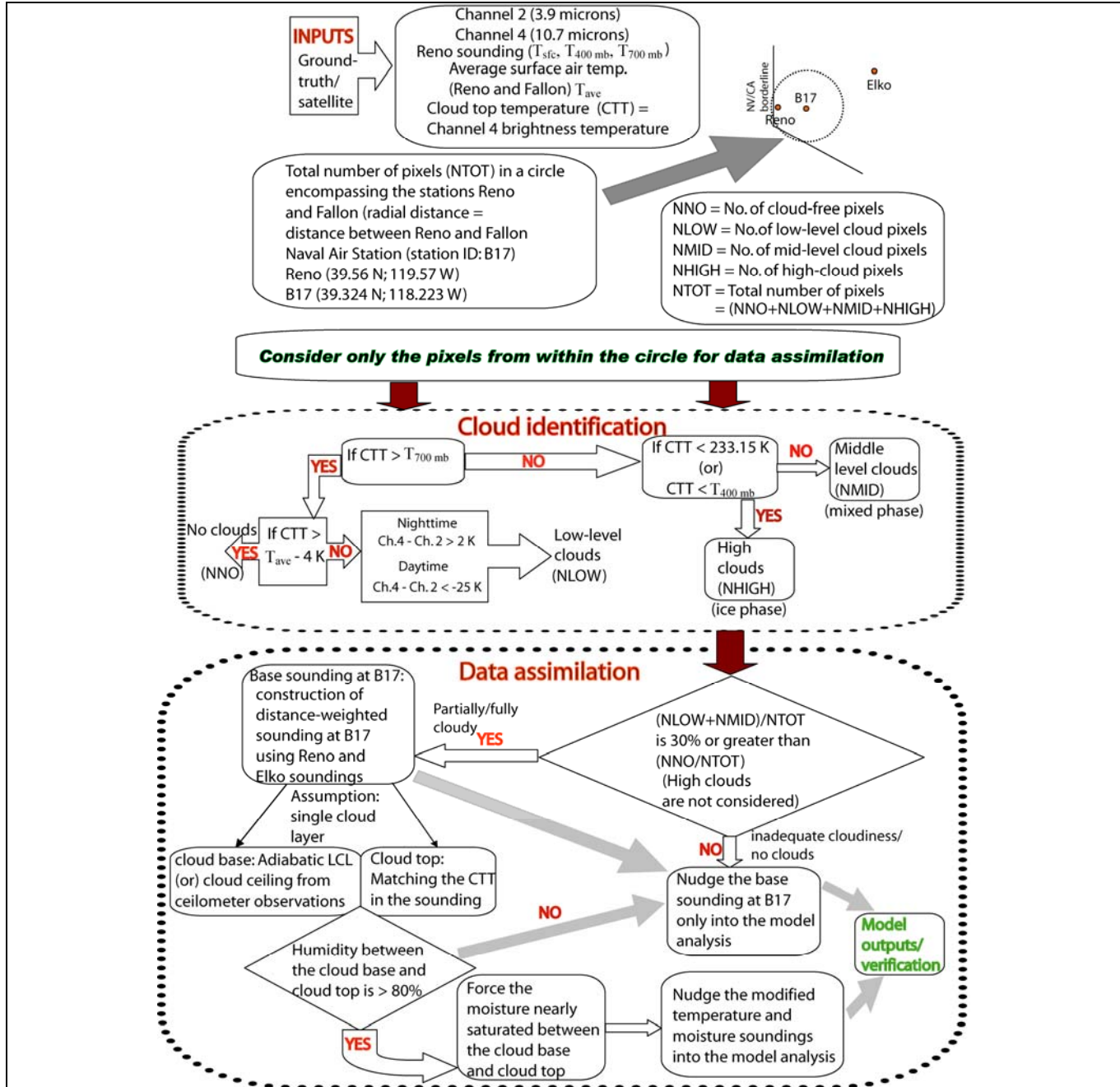


Figure 1. Flowchart for low- and middle level cloud identification and satellite data assimilation in the real time forecasting system.

WORK COMPLETED

To support real-time forecasting and nowcasting at the Fallon Naval Air Station, surface meteorological stations were operational during the project period. The location specifications of these sites are:

- Fallon 31ESE [NAS B17] at Centroid in Fairview Valley (39°19'27" N, 118°13'22" W, 4235' MSL). Location from NAS Fallon: 23 miles range at 99 degrees azimuth.
- Fallon 23SSE [NAS B19] at Blowing Sand Mountains (39°08'31"N, 118°40'01"W, 3886' MSL). Location from NAS Fallon: 16 miles range at 164 degrees azimuth.
- Fallon 36NE [NAS B20] at Carson Sink (38°54'40" N, 118°23'14" W, 3881' MSL). Location from NAS Fallon: 31 miles range at 13 degrees azimuth
- Fallon NAS EW71 Complex at Edwards Creek Valley (39°31'57" N, 117°44'50" W, 5192' MSL). Location of EW Complex: 11 miles NE of Cold Springs, NV

We have provided maintenance on these stations and additionally installed a sonic anemometer at the B17 station. The sonic anemometer has been in continuous operation since February 2007. The high frequency (20 Hz) flux and turbulence data from the sonic anemometers allow us to evaluate various turbulence parameterizations that are widely used in mesoscale models (MM5, COAMPSTM, and WRF). This will aid towards finding the optimally best turbulence parameterization that can be used for real-time forecasting in the Fallon area. Currently, we are comparing the sonic anemometer data against the MM5 results; however, in the future, similar methods can be applied to verify COAMPSTM forecasts of the turbulence kinetic energy (TKE) at the NAS Fallon.

The real-time MM5 system was developed and installed on an XD1 Cray computer at the Desert Research Institute. To account for synoptic processes and also to resolve the characteristics of the mesoscale processes, coarse and nested grids were set up to cover a large portion of the western U.S. The coarsest grid has a horizontal resolution of 27 km and encompasses most of the eastern Pacific Ocean and western United States; it has 103 x 103 grid points (23 synoptic sounding stations in the western and the central U.S. fall in this domain). The next grid has 103 x 103 points with a horizontal resolution of 9 km and covers Nevada and most of California, while the subsequent grids are each centered on Fallon, with resolutions of 3, 1, and 1/3 km. The third grid was of horizontal dimensions 103 x 103, while grids 4 and 5 were both comprised of 49 x 49 points. Each model domain consists of 40 layers where 23 layers were designated in the lowest 3 km for forecasts that are significant to aircraft operations.

The Four Dimensional Data Assimilation (FDDA; Stauffer and Seaman 1990) technique was applied to the data from the four special-network weather stations installed by DRI. The data from the stations are continuously transmitted to DRI's Western Regional Climate Center (WRCC) network and processed through the main quality assurance software. These data were set up as input to the 12-hr pre-forecasting time or model adjustment time in order to provide better initial conditions and subsequent improvement in the short-term forecasts (1-6 hrs) that are essential to the nowcasting objectives.

A version of this procedure modified for application to the Fallon Naval Air Station region of complex land surface has been developed and demonstrated (Vellore et al. 2006). Satellite data were provided by the Naval Research Laboratory (Monterey) in SeaSpace TeraScan TDF digital format.

Analysis of the model assimilation procedure and simulation results related to cloud cover can be accomplished using several output fields and derived parameters. Graphics of three-dimensional cloud field representations are produced and used for time-lapse animation that are directly compared with satellite image loops in multiple imaging channels (visible, infrared, near-infrared, and water vapor) and satellite composite products. Model predicted fields such as relative humidity provide information on the ability of the model to simulate vapor flux in the boundary layer. Model-generated vertical

profiles of cloud mass concentration have been essential in previous studies to interpret the influences of model resolution and initial conditions on thermodynamic evolution, particularly in the presence of temperature inversions. Vertically-integrated cloud and ice concentration, as computed column parameters, allow subjective and quantitative validation of critical conditions for restricted visibility in stratus, fog and ice fog events. Evaluation of these conditions also benefits from the availability of the turbulence kinetic energy observations and model results, for verification of the development of turbulent mixing as solar radiation transmittance through low cloud allows surface warming.

RESULTS

Regarding the efficiency of the real-time forecasting system, two situations were considered. One with respect to the number of processors, and the other is the selection of various physical parameterizations and model options. A series of model forecasts were conducted for evaluation. Figure 2 shows the clock time speed-up as a function of the number of processors.

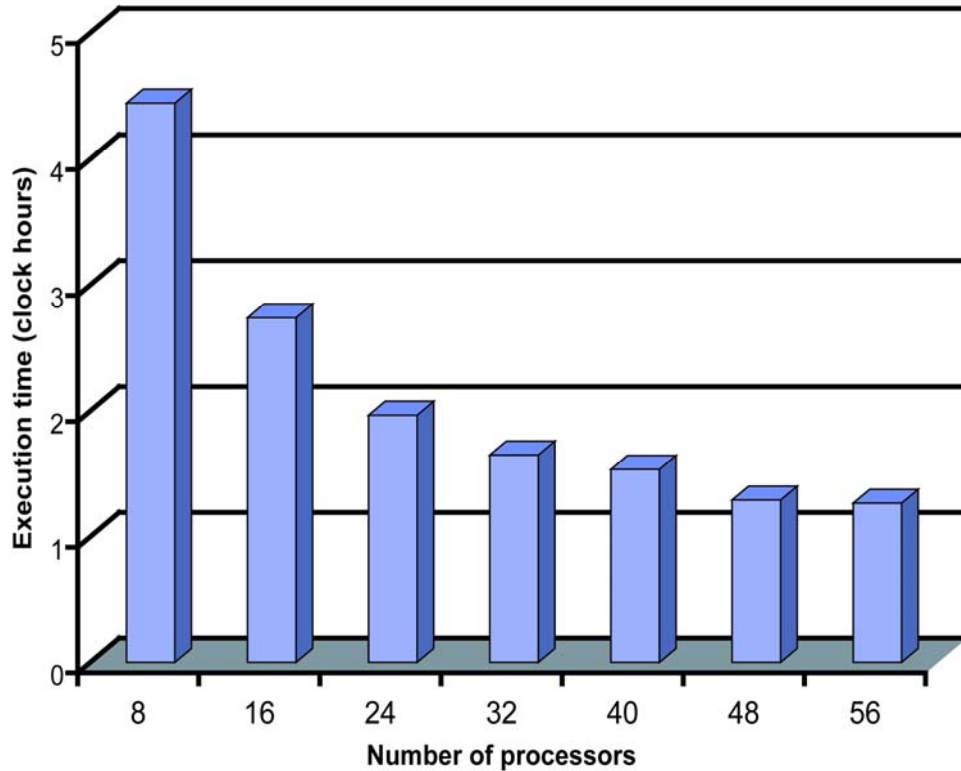


Figure 2. The execution time of a 24-hr real-time forecast as a function of number of processors (8-56).

Most of the benefit was gained by increasing the number of processors from 8 to 16 and then to 24. For the second case (sensitivity to various model parameterizations), we have run a baseline case (shown in Table 1) and then varied options related to the physical parameterizations of shallow convection, cumulus formation, two microphysical packages, three turbulence transfer schemes, and a radiation scheme (Fig. 3).

Table 1. Physical parameterizations used in the model base configuration

Cumulus parameterization	Grell scheme (only on 27 and 9 km grids)
Cloud microphysics	Reisner's simple explicit microphysics (five hydrometeors) (water vapor, cloud water, rain water, cloud ice, and snow)
PBL physics	Gayno-Seaman scheme
Radiation	Dudhia scheme (shortwave and longwave)
Two-way nesting	Feed back with strong smoothing

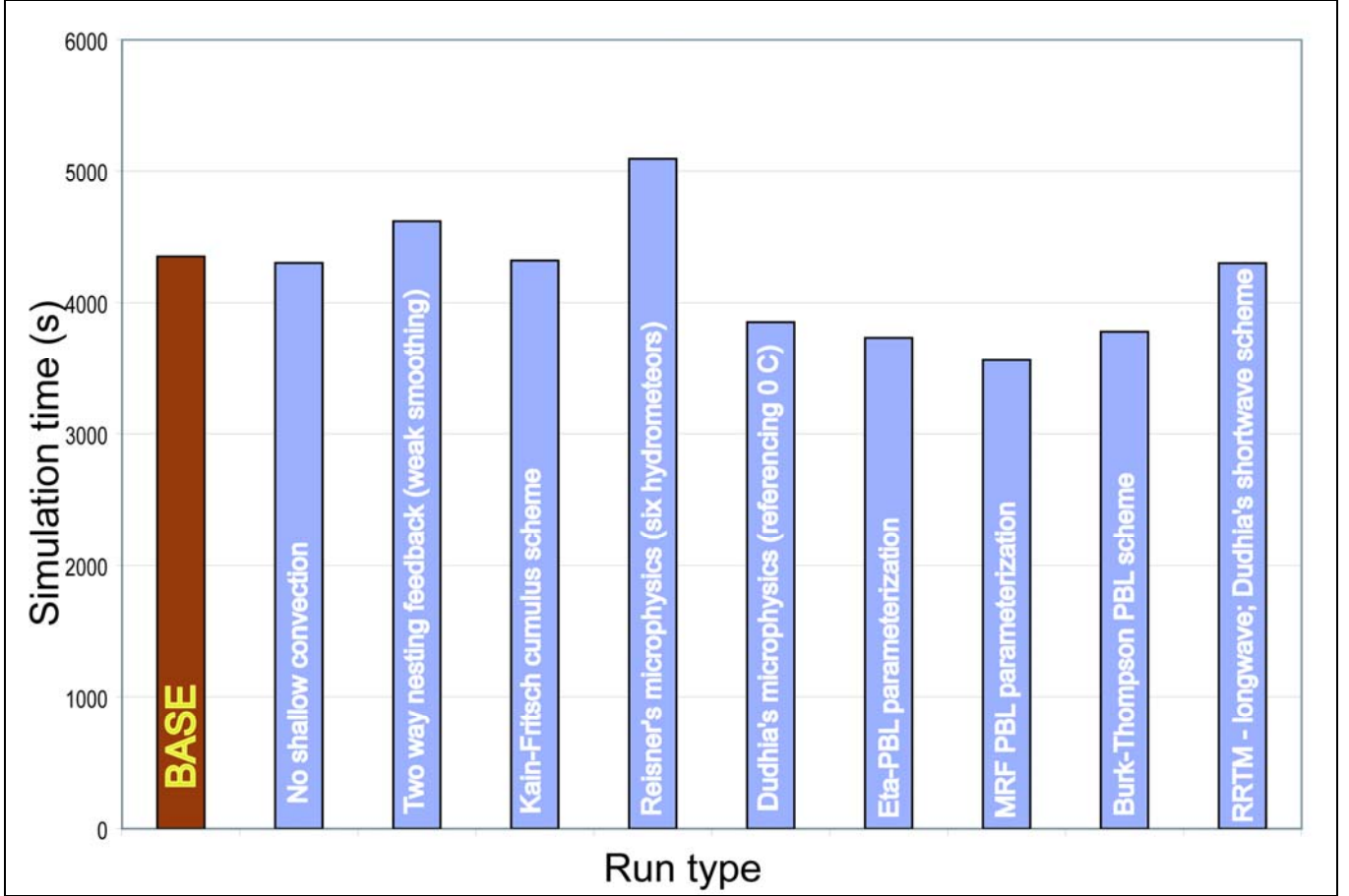


Figure 3. Real-time forecasting execution time with respect to the optional parameterizations.

Figure 3 shows that the choice of the microphysical parameterizations significantly influences the execution clock time, while the optional turbulence parameterizations show similar weight on the execution time. This behavior is due to the extra computational time used by the complex calculations in the additional prognostic computations of hydrometeors and number concentration. The options of turbulence parameterizations, either local or non-local, 1.5 order Mellor-Yamada type (the Eta-PBL scheme; used in the operational NCEP Eta model) or schemes that include second order moments (the Burk-Thompson scheme; used in COAMPSTM) showed similar weight on the execution time. Also, complex radiation modules such as the Rapid Radiative Transfer Model (RRTM) based radiative computations rates did not significantly alter the simulation time with reference to the base run which used a simple type of radiative scheme for the longwave radiation. Strong or weak smoothing in the

nesting feedback of dynamical variables did not show significant difference from the base run; however, it is suggested by the MM5 community users that we use the nesting feedback with strong smoothing in combination with MPI for better performance (mesouser@ucar.edu).

Regarding a new method of satellite data assimilation, we show two products: determination of cloud types, and improvement in the surface temperature forecasts as a consequence of more realistic initial boundary layer structure. An example of the satellite data assimilation evaluation for the 24 April 2006 forecast is shown in Figs. 4 and 5. This case was characterized by scattered cloudiness and mainly clear-sky conditions at the NAS Fallon airport area. As indicated by Fig. 5, the difference between the cloud top temperature and the measured surface temperature indicates that the clouds were generally absent at the time for which the simulated contours of the integrated liquid water path are shown in Fig. 4. Without assimilating satellite data, the model significantly overestimated cloudiness and underestimated the surface temperature (Fig. 5). The satellite data assimilation definitely improved the forecasts of cloudiness and consequently air temperature in the boundary layer.

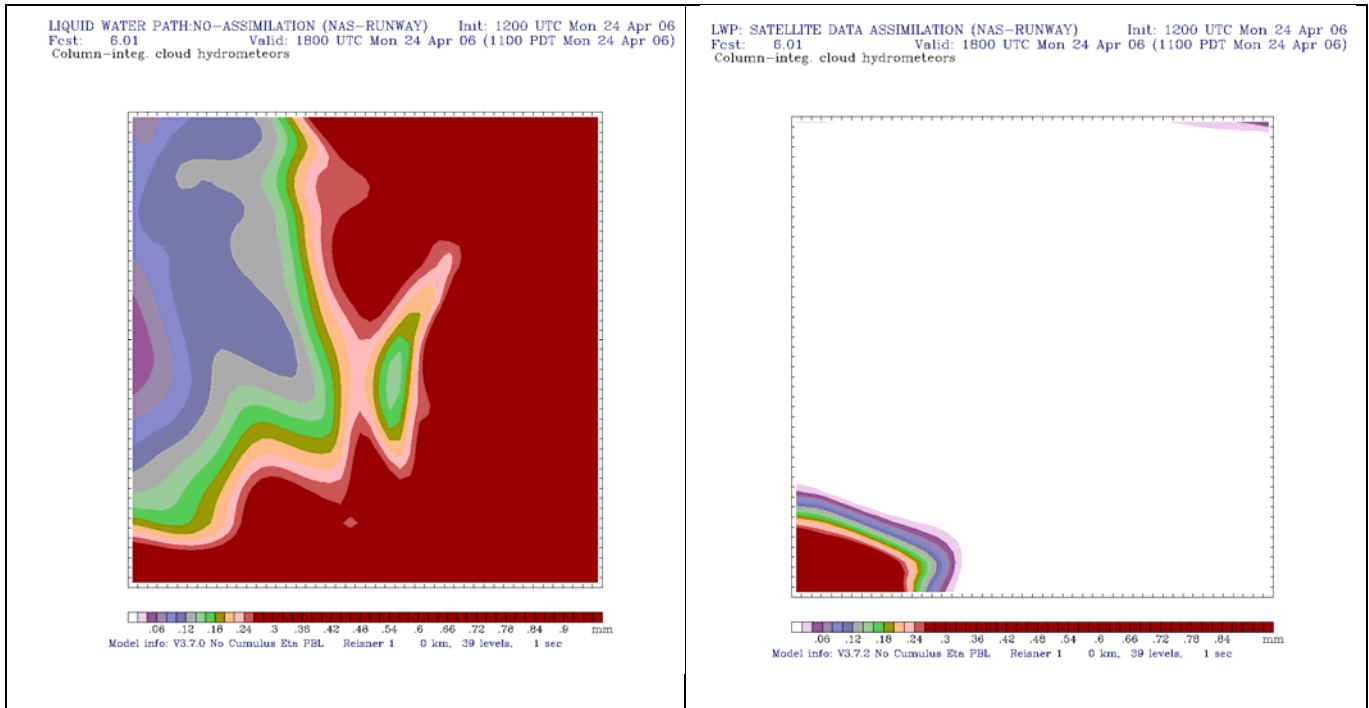


Figure 4. Contour plots of the integrated liquid water path for 1800 UTC on 24 April 2006 without (left panel) and with (right panel) satellite data assimilation in the real-time forecasting system.

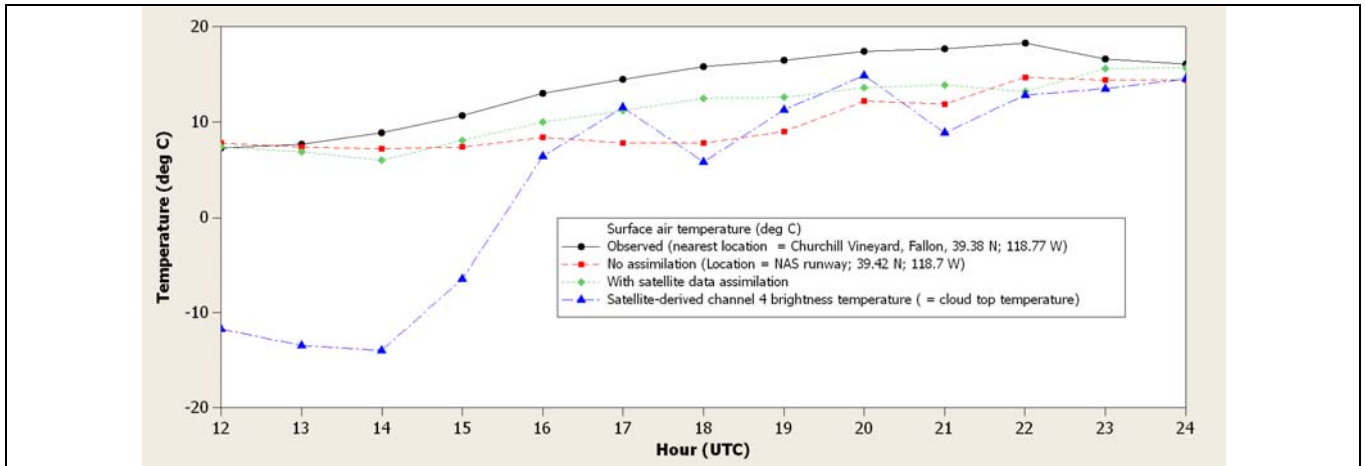


Figure 5. *Observed surface temperature, satellite-measured cloud top temperature, and simulated time series of air temperature at the surface for the simulations initialized at 1200 UTC on 24 April 2006.*

Installation of the sonic anemometer at the NAS Fallon station B 17 allowed us to evaluate turbulence parameterizations that are used in MM5 and other models. MM5 employs three turbulence parameterizations that predict the evolution of TKE. Figure 6 shows a comparison of the measured and simulated TKE for a period of 3 days (April 3-6, 2007). We tested three commonly used turbulence parameterizations, namely Gayno Seaman (widely tested and applied in the study of low clouds and fog, Vellore et al. 2007), the Eta-PBL scheme, and the Burk-Thompson parameterization.

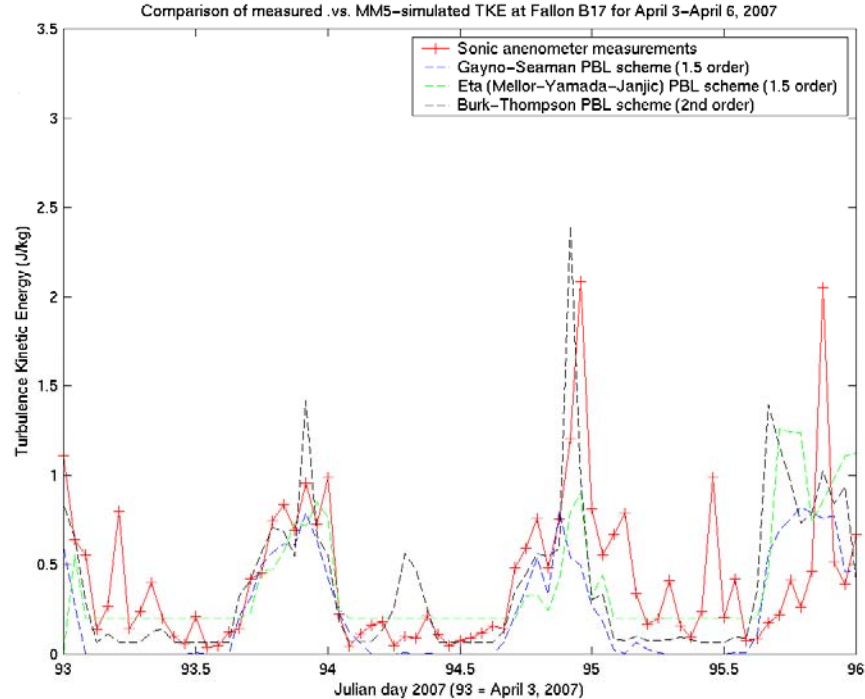


Figure 6. *Turbulence kinetic energy (TKE) as measured by the sonic anemometer and simulated by MM5 (3 km grid) using the Gayno Seaman, Eta-PBL and Burk-Thompson PBL schemes at Fallon station B17 for the period from 3-6 April 2007 (Julian day 93 refers to April 3, 2007 at 0000 UTC).*

Besides sharp peaks, mainly as a consequence of sonic's high sampling rate (20 Hz), both schemes show reasonable resemblance to the data. For this limited sample the model shows quite good agreement generally for all schemes; however, this needs to be evaluated for longer time samples during various weather conditions.

Regarding the predictability study, we set up a sequence of the lag-forecasting runs (Fig. 7) for a dust storm case in February 2002 to address the principal question of how close the ensemble members are with respect to measurements.

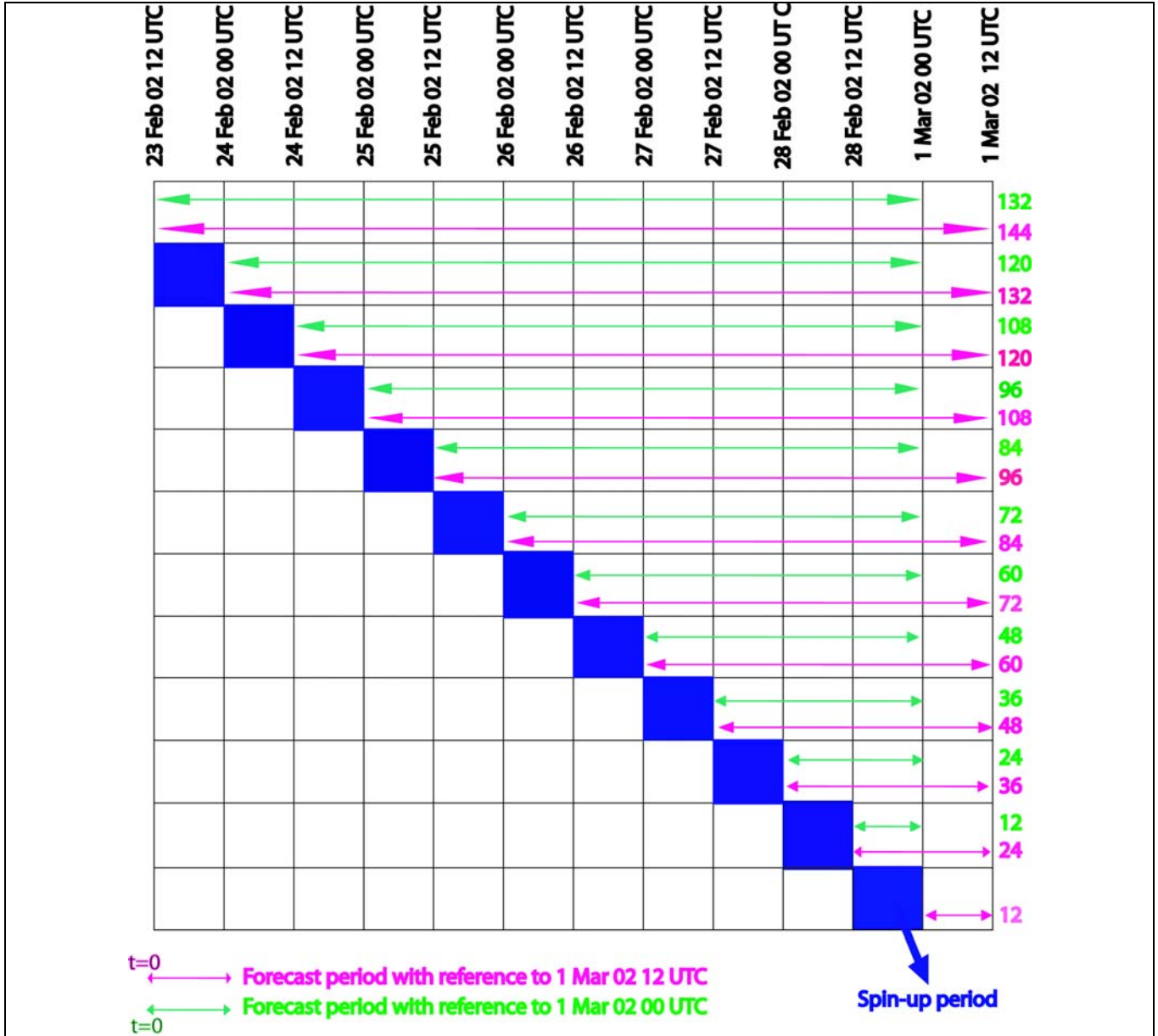


Figure 7. Schematic of the lag-forecasting setup to provide forecasts on 1 March 2002 at 1200 UTC. Each run includes a 12 hr spin-up (pre-forecast) period.

Figure 8 shows the spread of the ensemble members composed from the lag-forecasting runs for the temperature at 700 hPa and 500 hPa levels.

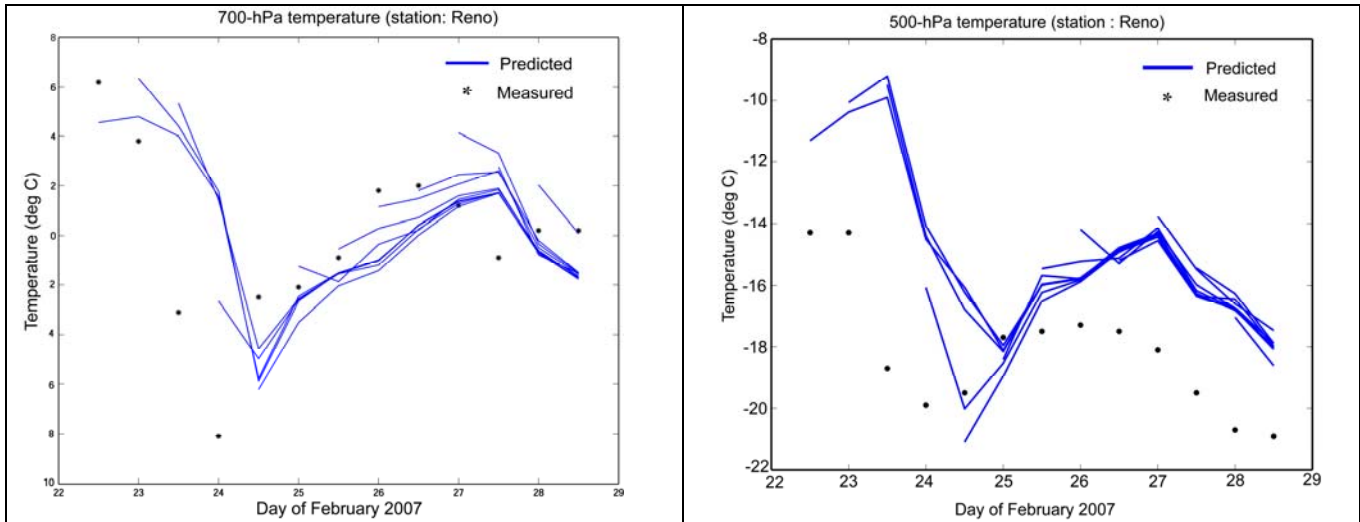


Figure 8. Measured (symbol) and predicted (using the lag-forecasting runs) (solid line) air temperature at 700 hPa (left panel) and 500 hPa (right panel) at the Reno radiosonde location. The left end of the each forecast line is a start time of the forecast and the right end of the line is the end of that particular run.

The figure shows that the lag-forecasting runs provided a useful spread that allows the ensemble average to come close to the measurements. To compare with standard methods of examining model's behavior at the 500 hPa level, we selected 23 radiosonde stations in the western U.S. and computed the root-mean-square error (RMSE) and index of agreement (IA) (Willmott 1982; Fig. 9). Future studies should focus on developing new methods for creating a viable set of initial perturbations for mesoscale simulations in combination with the LAF method to provide probabilistic forecasting for longer forecast lead time for the Fallon area.

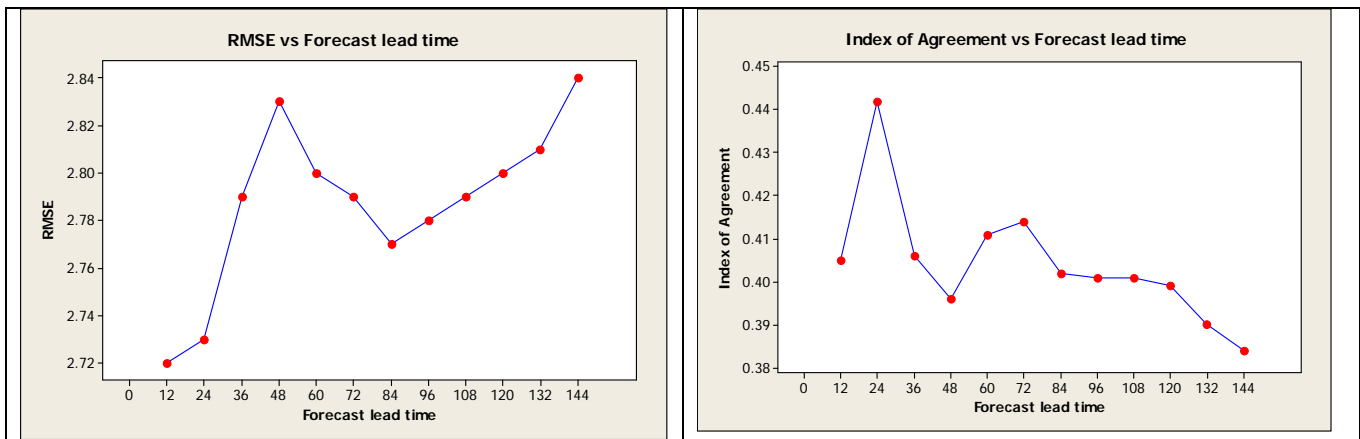


Figure 9. Root-mean-square error (left panel) and the index of agreement (right panel) of the simulated temperature at the 500 hPa level vs. forecast lead time as computed from the 23 radiosonde stations' data in the western U.S. The range of the index of agreement is 0 for a no-skill forecast and 1 for a perfect forecast.

Figure 9 shows that, although the RMSE shows a general trend of increasing values for greater lead time (as would be expected), the variations in the mid range lead time (essential for the conventional forecasting time scale; 24-48h) indicate characteristics that need to be explored further. It is possible

that the mesoscale models need more time to capture the complete evolution of complex weather storm systems (as also seen in Fig. 8). The IA indicates that the highest model accuracy is within the first 24 hrs, but there is again an increase in the IA in the mid range before decreasing for greater lead time.

Bearing in mind the complexity of 4-D forecast models, we additionally provided the first attempt to find better and faster ways of interpreting and searching forecast results by using advanced methods of model visualization. An example is shown in Fig. 10. This visualization system can be a useful tool for a time-efficient and perception-rich search through large forecast outputs in particular areas of interest and flight patterns by personnel (pilots, meteorological support staff, etc.) who do not need to have any technical knowledge of the forecast or/and visualization technical aspects.



Figure 10. Visualization of the real-time forecasts of turbulence and cloudiness over the runway for the Fallon NAS in the CAVE (Cave Automatic Virtual Environment). A person in the CAVE can interactively probe forecast results with respect to various model domains, times, and forecasted parameters. For this visualization, white represents cloud, while cyan represents areas of high turbulence kinetic energy.

RELATED PROJECTS

Dr. Koracin is a P.I. on a project supported by another ARO grant that is focusing on visualization and virtual reality applications of the Fallon NAS high-resolution mesoscale forecasts. Dr. Koracin is a co-P.I. on ARO Project entitled “Forecasting of Desert Terrain” where real-time experience and expertise is facilitating an interdisciplinary project linking dust emission modeling, atmospheric predictions and Lagrangian Random Particle Dispersion modeling. Drs. Wetzel and Koracin are also co-P.I.s on a multi-institutional NSF-EPSCoR Project on Cognitive Information Processing: Modeling and Inversion where they are developing new methods of satellite data assimilation and investigation of predictability and chaos in numerical weather and climate forecasting.

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